Method of reducing a peak-to-average power ratio

This invention is based on a priority application EP 03 290 602.6 which is hereby incorporated by reference.

Field of the invention

The present invention relates generally to a system and method for transmitting digital signals, and more particularly without limitation to clipping techniques for reduction of the peak-to-average power ratio of multi-carrier multiplexed signals, such Orthogonal Code Division Multiplex (OCDM), or Orthogonal Frequency Division Multiplex (OFDM) signals.

Background of the invention

A large peak-to-average power ratio reduces the efficiency of a transmission power amplifier. In particular this is a problem for multi-carrier multiplexed signals such as OCDM and OFDM signals as for such signals the maximum possible peak power is much larger than the average transmitted power.

US Patent No. 6,175,551 shows a method for reduction of the peak-to-average power ratio by means of soft-clipping. Soft-clipping means that a scaled reference function is subtracted from the sampled signal, such that each subtracted reference function reduces the peak power of at least one signal sample. Preferably the reference function has approximately or exactly the same bandwidth as the transmitted signal. In this way it is assured that the peak power reduction does not cause any out-off band interference. One example of a suitable reference signal is a sinc function.

A common disadvantage of prior art soft-clipping methods is that the subtraction of the reference function from the over shooting signal portion can result in multiple maxima. This problem of the prior art is illustrated by making references to figures 1 to 3:

Figure 1 shows the magnitude signal 100 of an I,Q signal to be transmitted. Signal 100 has portions which are above clipping threshold 102. Those portions of signal 100 respective peaks are detected and marked by peak markers 104 to 114.

Figure 2 shows reference signal 116 in the time domain. Scaled reference signal 116 is subtracted from the I and Q components of signal 100 at the peak locations which are identified by peak markers 104 to 114. The result of this soft-clipping operation is shown in figure 3 where magnitude signal 118 is the clipped signal.

For example, the first peak of signal 100 which is identified by peak marker 104 is transformed into two new peaks 120 and 122 of signal 118. Likewise a large number of new peaks is created in the signal portion consisting of the peaks identified by peak markers 108 to 114. Hence additional soft-clipping iterations are required to interatively bring signal 100 to clipping threshold 102.

Therefore the present invention aims to provide an improved method of reducing a peak-to-average power ratio of a signal to be transmitted for improved soft-clipping.

Summary of the invention

The present invention provides for a method of reducing a peak-to-average power ratio of a signal to be transmitted by decomposing portions of the signal which are above a clipping threshold level into elementary functions. The elementary functions provide the locations and the amplitudes for soft-clipping of the original signal. This enables to substantially reduce the number of iterations which are required for the soft-clipping.

In accordance with a preferred embodiment of the invention only a single soft-clipping step is performed on the decomposed portions of the signal completely avoiding multiple soft-clipping iterations.

In accordance with a further preferred embodiment of the invention, symmetric functions are used for decomposing of the signal portions, such as gaussian or triangle functions.

In accordance with a further preferred embodiment of the invention only the amplitudes and the positions of the functions are parameterised for decomposing of the portions of the signal which are above the clipping threshold level. This reduces the computational complexity of the decomposition process.

In accordance with a further preferred embodiment of the invention only a single type of elementary function is used for decomposing of the signal portions.

It is to be noted that the present invention can be used for any sender, such as an end-user telecommunication device, a transmitter, such as a base station of a wireless cellular telecommunication network and other telecommunication applications.

Brief description of the drawings

In the following preferred embodiments of the invention will be described in greater detail by making reference to the drawings, in which:

Figure 1 shows a signal which has portions above a clipping threshold,

Figure 2 shows a reference function for performing soft-clipping,

Figure 3 shows the signal of figure 1 after performing one iteration of soft-clipping by means of the reference function of figure 2,

Figure 4 shows an example of a portion of a signal to be transmitted which is above the clipping threshold,

Figure 5 shows the decomposition of the signal of figure 4 into elementary gaussian functions,

Figure 6 shows a portion of a block diagram of a transmitter.

Detailed description

Figure 4 shows peak 400 of a signal to be transmitted in the time domain. Peak 400 is a magnitude signal and is above a clipping threshold level.

Peak 400 is decomposed into gaussian functions 500, 502 and 504. The number of the gaussian functions which is used to perform the decomposition is chosen in proportion to the duration of peak 400. To perform the soft-clipping a reference function, such as the function shown in figure 2, is used.

The positions for subtracting of the reference function are given by the positions of the elementary functions into which the peak 400 is decomposed. The scaling of the reference function at those positions is determined by the amplitudes of the corresponding elementary functions. This way only one or a small number of iterations are required to bring peak 400 to the clipping threshold.

In more general terms a peak P of a signal to be transmitted which is above the clipping threshold level is developed as a sum of elementary functions f:

$$P = \sum_{i=1}^{N} f(x_i, A_i)$$

where N is the number of elementary functions which is proportional to the duration of the peak P, x_i the position of the maxima of the elementary functions and A_i the amplitudes at the positions of the maxima x_i.

For example a gaussian function can be used as elementary function f or another symmetric function, such as a triangle function.

In the example shown in figure 5 a gaussian function is used as elementary function f. The first gaussian function 500 which is used for the decomposition of peak P is positioned at x_1 and has amplitude A_1; gaussian function 502 is positioned at x_2 and has amplitude A_2; gaussian function 504 is positioned at x_3

and has amplitude A_3. The number N is equal to 3 in the example considered here as a number of 3 elementary functions is used for the decomposition.

Hence, soft-clippings are performed at positions x_1, x_2 , x_3. For the soft-clipping on position x_1 the reference function is scaled in proportion to the amplitude A_1. Likewise, for the soft-clipping on position x_2 the reference function is scaled in proportion to the amplitude A_2, etc.

In general, the decomposition of the peak P into a number of N elementary functions can be performed by means of mathematical methods which are as such known. For example the decomposition can be performed by finding a minimum for

$$[P - \sum_{i=1}^{N} f(x_i, A_i)]^2$$

Alternatively the absolute value, i.e.

$$| P - \sum_{i=1}^{N} f(x_i, A_i) |$$

can be used.

An example for a mathematical method which can be used for performing the decomposition is the gradient method.

Figure 6 shows a portion of a block diagram of transmitter 600. Transmitter 600 has multi- carrier synthesis module 602 to provide a multi-carrier multiplexed signal 604, such as an OFDM or OCDM signal.

Further transmitter 600 has peak detection module 606 which outputs those portions of signal 604 which are above a clipping threshold level. These peaks are provided from peak detection module 606 to peak decomposition module 608, where the peaks are decomposed into elementary functions as explained

above. The result of the peak decomposition is provided from peak decomposition module 608 to soft-clipping module 610. In soft-clipping module 610 a reference function is subtracted from the peak at the positions of the elementary functions; the respective scalings of the reference function are determined by the amplitudes of the elementary functions. The resulting soft-clipped signal is then sent out by transmitter 600 over an air-interface or a cable connection.

List of Reference Numerals

100	signal
102	clipping threshold
104	peak markers
106	peak markers
108	peak markers
110	peak markers
112	peak markers
114	peak markers
116	reference signal
118	signal
120	peak
122	peak
400	peak
500	gaussian function
502	gaussian function
504	gaussian function
600	transmitter
602	multi carrier synthesis module
604	signal
606	peak detection module
608	peak decomposition module
610	soft-clipping module